

**N91-14403**

VII-2

## **Growth and Properties of Hg-Based Quantum Well Structures and Superlattices**

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Department of Physics, North Carolina State University, Raleigh, NC 27695-8202

An overview of the properties of HgTe-CdTe quantum well structures and superlattices will be presented. These new quantum structures are candidates for use as new LWIR and VLWIR detectors, as well as for other optoelectronic applications. Much as been learned within the past two years about the physics of such structures. The valence band offset has been determined to be  $\sim 350$  meV, independent of temperature. The occurrence of electron and hole mobilities in excess of  $10^5$  cm<sup>2</sup>/V·s is now understood on the basis of SL band structure calculations. The in-plane and out-of-plane electron and hole effective masses have been measured and interpreted theoretically for HgTe-CdTe superlattices. Controlled substitutional doping of superlattices has recently been achieved at NCSU, and modulation-doped SLs have now been successfully grown and studied. Most recently, a dramatic lowering of the growth temperature of Hg-based quantum well structures and SLs (to  $\sim 100$  C) has been achieved by means of photoassisted MBE at NCSU. A number of new devices have been fabricated from these doped multilayers.

Work supported by NSF grant DMR-88-13525 and NRL contract N00014-89-5-2024.

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# **GROWTH AND PROPERTIES OF Hg-BASED QUANTUM WELL STRUCTURES & SUPERLATTICES**

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**Department of Physics**

**North Carolina State University, Raleigh, NC**

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**NCSU II-VI SEMICONDUCTOR MBE PROGRAM  
Collaborators and Students at NCSU**

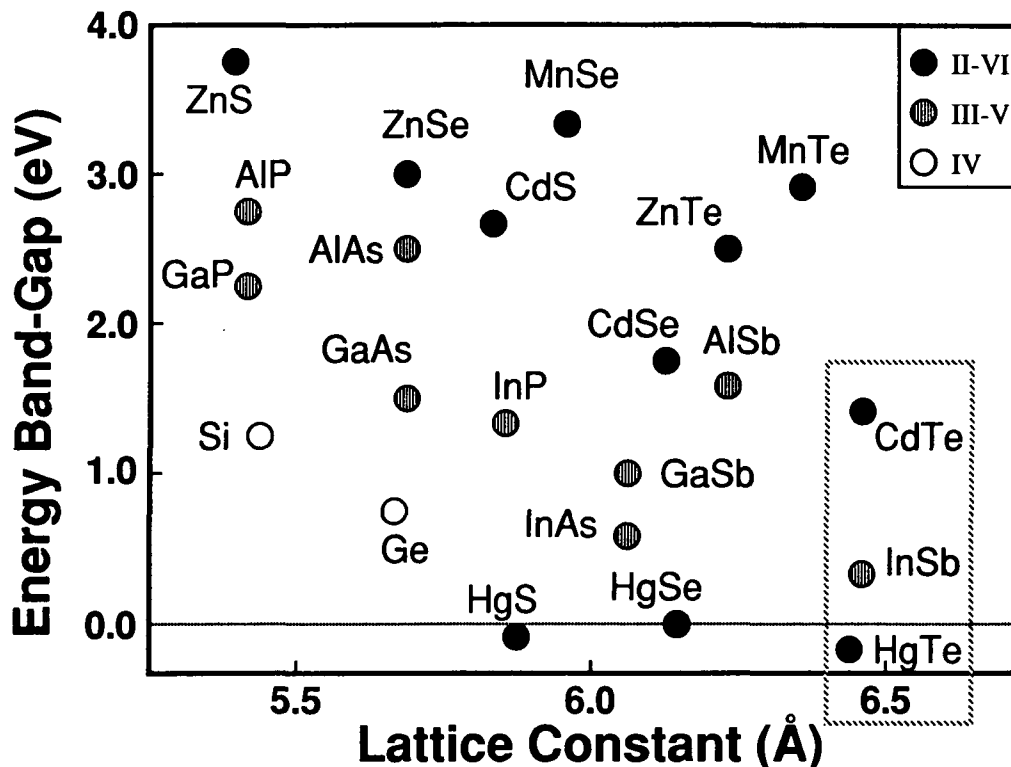
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|--|--|
| <ul style="list-style-type: none"><li>• <b>Research Associates</b><br/>N.C. Giles<br/>S. Hwang<br/>Z. Yang<br/>J. Yu</li></ul>               | <ul style="list-style-type: none"><li>• <b>Technicians</b><br/>J. Matthews<br/>B. Sneed<br/>K. Bowers</li></ul>            |
| <ul style="list-style-type: none"><li>• <b>Graduate Students</b><br/>D. Dreifus<br/>J. Han<br/>Y. Lansari<br/>R. Vaudo<br/>R. Reed</li></ul> | <ul style="list-style-type: none"><li>• <b>Secretary</b><br/>T. Hockenberger</li><li>• <b>Undergraduates (4)</b></li></ul> |

# OVERVIEW OF PRESENTATION

- Photoassisted MBE at NCSU
  - Experimental Procedures
  - Summary of Materials Properties
- HgTe-CdTe Superlattices
  - Growth of VLWIR Structures (18 - 22  $\mu\text{m}$ )
  - Controlled Doping Studies
  - Low Temperature Processing at NCSU
- Applications
  - Sources & Detectors
  - Amplifiers & Modulators

## ENERGY BAND GAP vs LATTICE CONSTANT OF SELECTED SEMICONDUCTORS

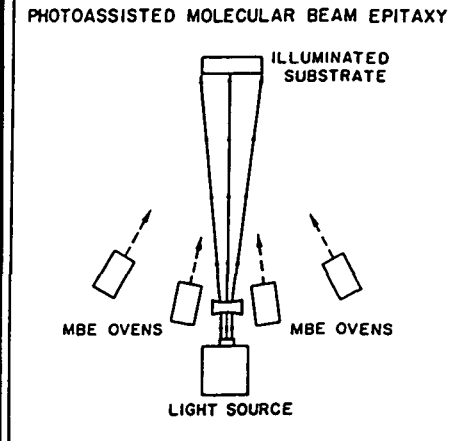


# PHOTOASSISTED MOLECULAR BEAM EPITAXY

## A New Approach to Controlled Substitutional Doping

R.N. Bicknell, N.C. Giles, and J.F. Schetzina  
Appl. Phys. Lett. 49, 1095 (1986)

- A Form of Energy-Assisted Epitaxy
- Growth Temperatures of II-VI Compounds are Low (150 - 350 °C)
- Photons Provide a Source of High Energy, Low Momentum Particles that Bathe the Substrate Surface during Film Growth & Induce Photochemical Reactions
- "Its all done with MIRRORS!!!"



## SUBSTITUTIONAL DOPING OF II-VI SEMICONDUCTORS

### Major Long-Term Problems

- **Poor Quality Bulk Crystals & Substrates**
- **Large Dislocation Densities**
- **Large Densities of Native Defects**
- **Low Percentage of Dopant Activation**
- **Compensation Effects Often Dominate**
- **Poor Electrical Properties - Low Mobilities**
- **Inferior Optical Properties - Deep Levels**

# **PHOTOASSISTED MOLECULAR BEAM EPITAXY**

## **Microscopic Mechanisms**

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- **Conversion of Surface Molecules into Atoms**
- **Photochemical Changes in Atomic Bonding**
- **Enhancement of Surface Mobility of Atoms**
- **Photochemical Activation of Dopant Atoms**
- **Modification of Stoichiometry of Growth Surface**

# **PHOTOASSISTED MOLECULAR BEAM EPITAXY**

## **MBE Film Growth Systems at NCSU**

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### **SYSTEMS DESIGNED AND CONSTRUCTED AT NCSU**

- **Custom Features for II-VI Materials**
  - **Cost Effective**

### **MBE FACILITIES**

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- **Three Hg-Compatible Systems**
- **One System for Wide Gap II-VIs**
- **Special Hg Sources (NCSU)**
- **Two-Zoned Furnaces (NCSU)**
- **Computer-Controlled Shutters**
- **Spectra Physics Argon Ion Laser**

# PHOTOASSISTED MOLECULAR BEAM EPITAXY

## WIDE-BAND-GAP & NARROW-BAND-GAP II-VIs

MATERIALS GROWN		PROPERTIES
CdTe:In	CdMnTe:In	• Controlled Doping
CdTe:Sb	CdMnTe:Sb	• High Carrier Mobilities
CdTe:As	HgCdTe	• Narrow Rocking Curves
CdMnTe-CdTe Superlattices		• Bright Photoluminescence
HgTe-CdTe Superlattices		• p-n Junctions Fabricated
Modulation-Doped HgCdTe		• FETs Fabricated

## HgTe-CdTe SUPERLATTICES

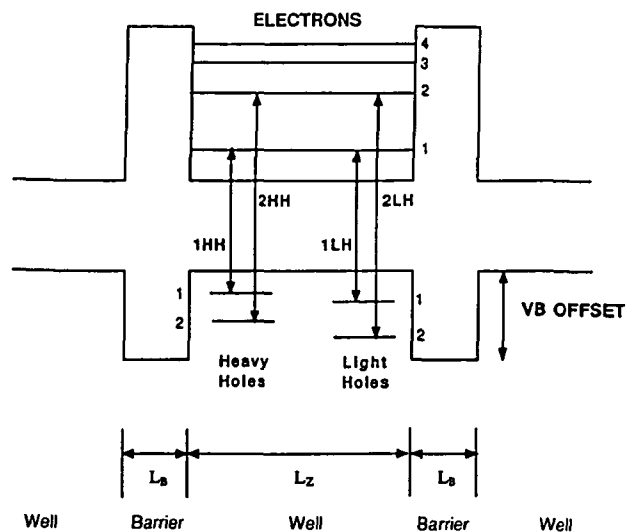
### Growth Parameters

SUBSTRATE:	(100) CdZnTe
SUBSTRATE TEMPERATURE:	150 °C
	140 °C (Photoassisted)
T <sub>In</sub> :	400-475 °C
T <sub>As</sub> :	220 °C
Hg FLUX:	1.5 X10 <sup>-4</sup> Torr
DEPOSITION RATE:	1-3 Å/sec
LAYER THICKNESSES:	
	HgTe 32-160 Å
	CdTe 26-102 Å

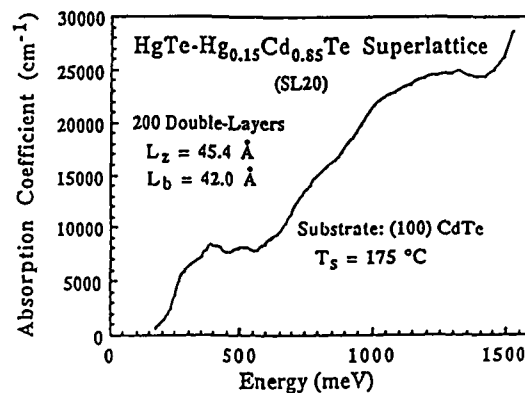
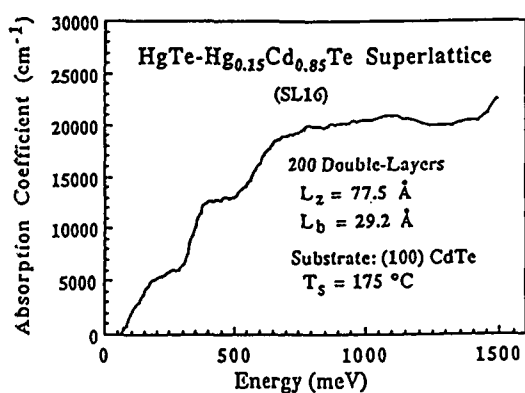
# Hg Te-CdTe SUPERLATTICES

## Designation of Electronic Transitions

### QUANTUM TRANSITIONS IN MULTILAYERS

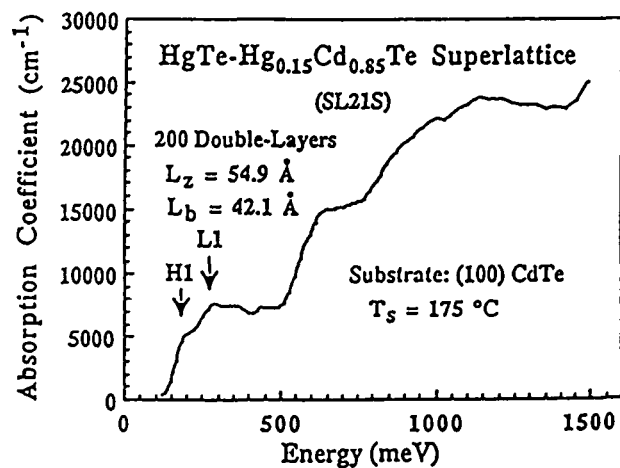
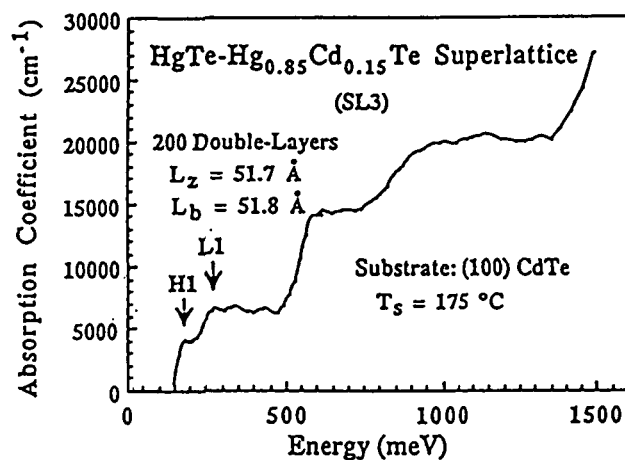


## Optical Properties

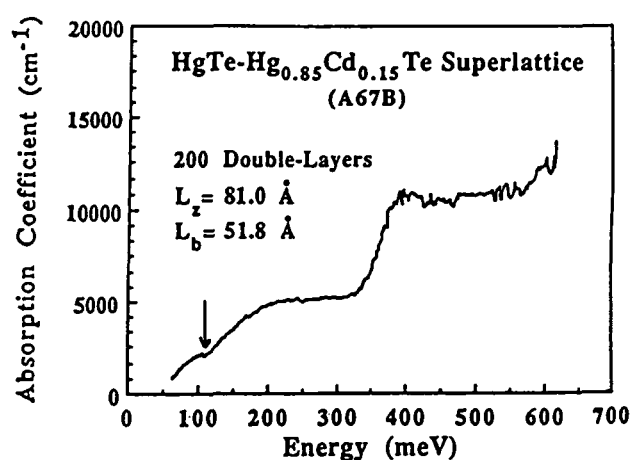
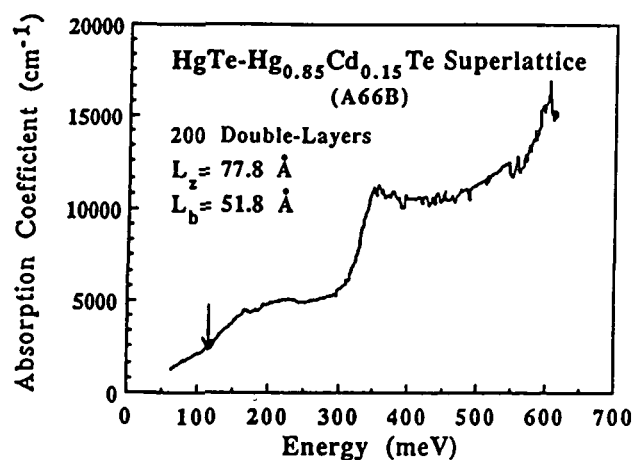


# HgTe-CdTe SUPERLATTICES

## Optical Properties



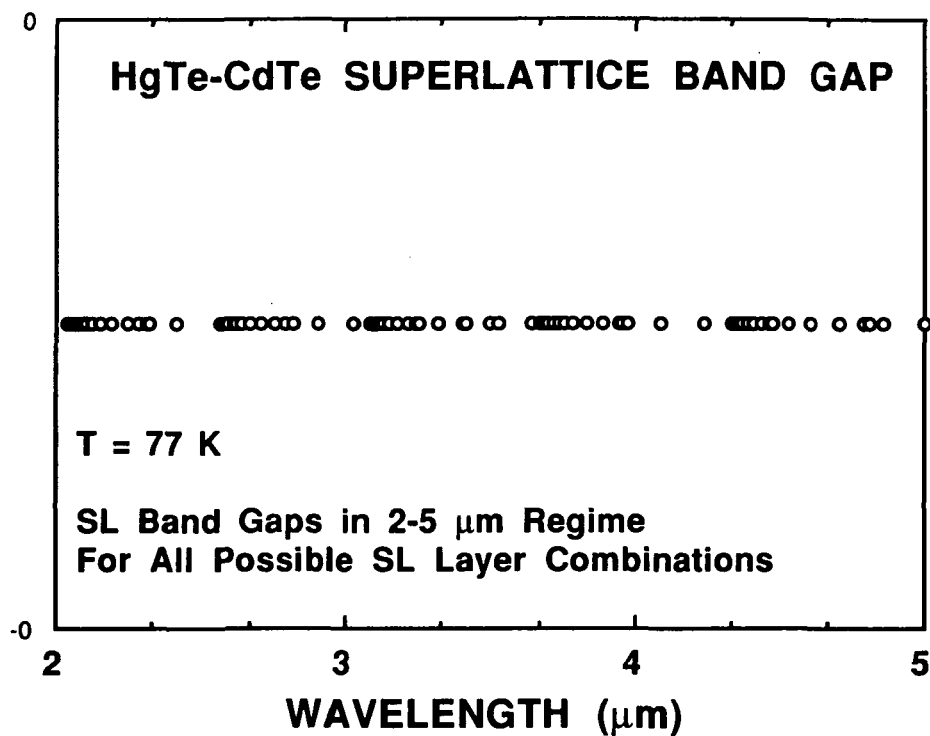
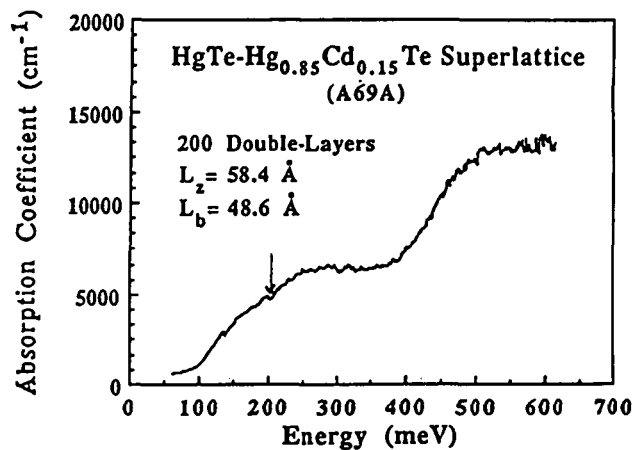
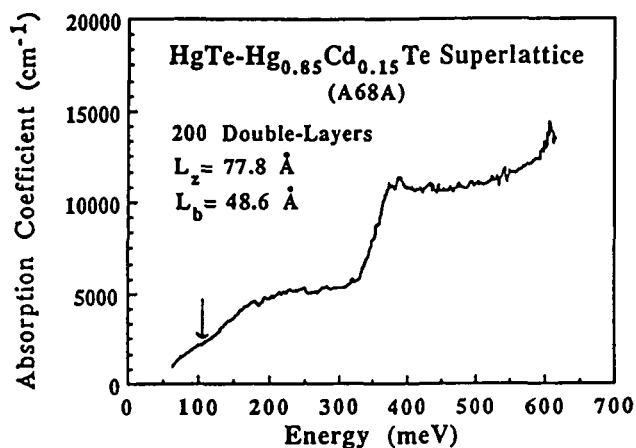
## Optical Properties: VLWIR Structures

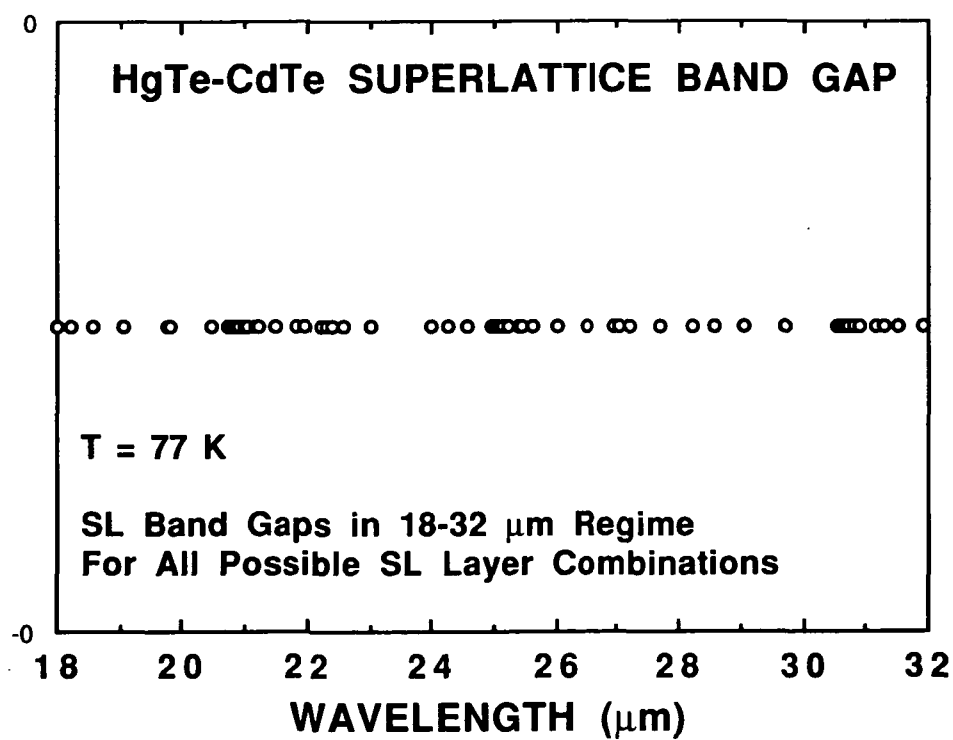
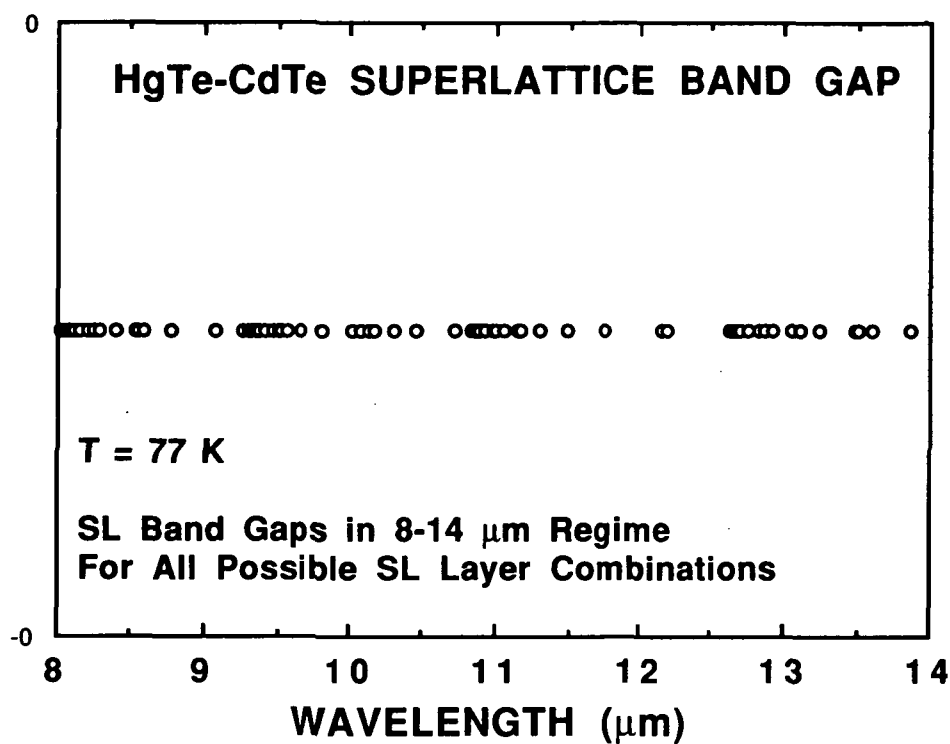


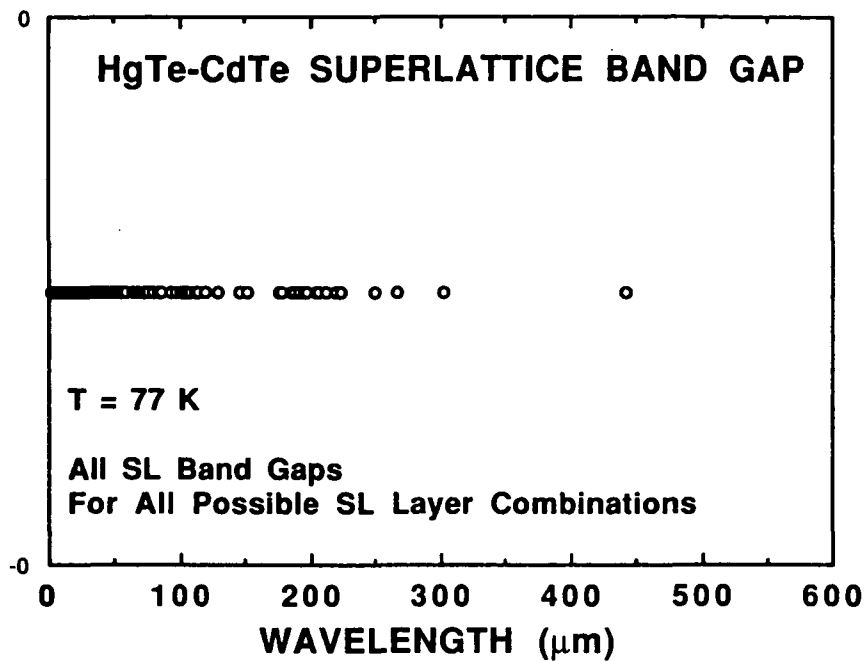


# HgTe-CdTe SUPERLATTICES

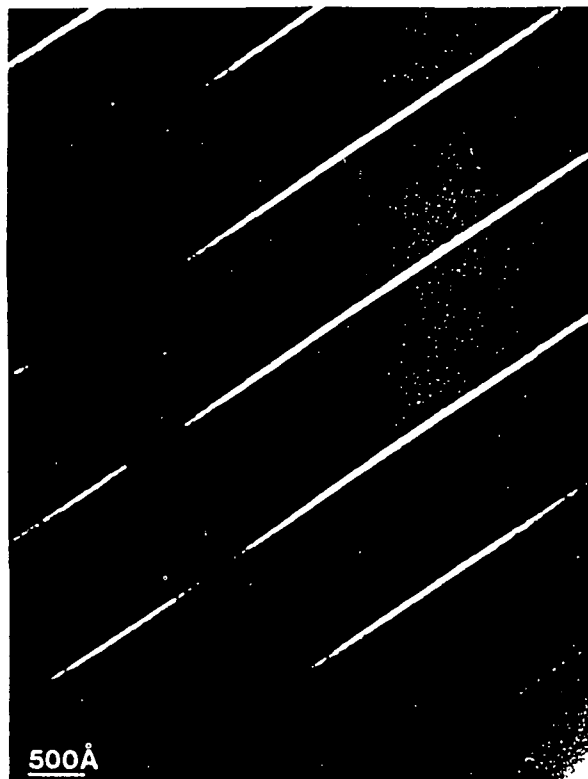
## Optical Properties: VLWIR Structures







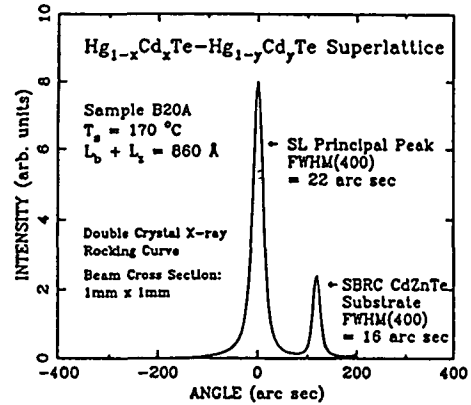
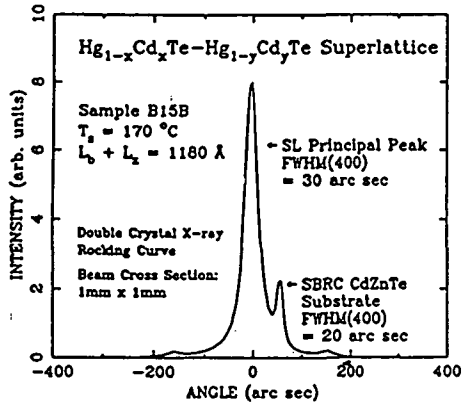
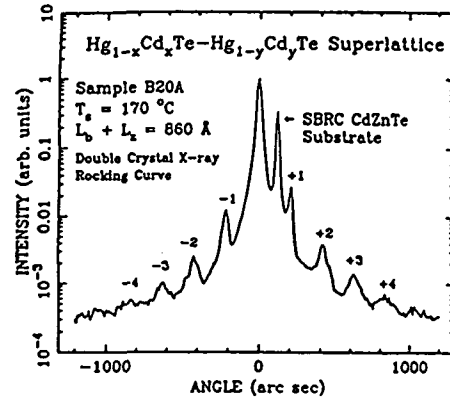
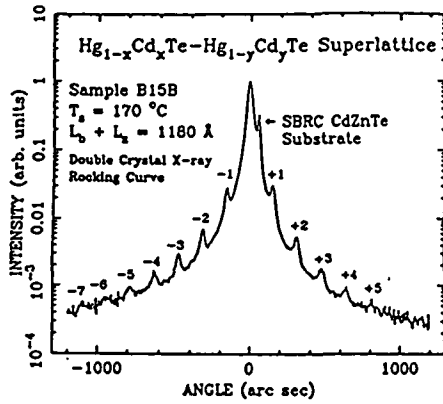
Vertical Cross-Section TEM Photo  
of Modulation Doped HgCdTe



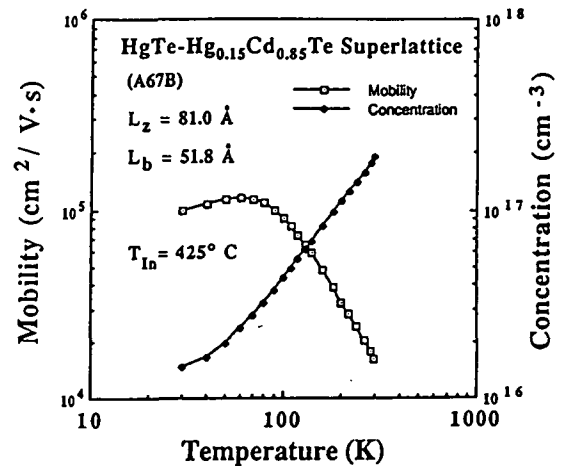
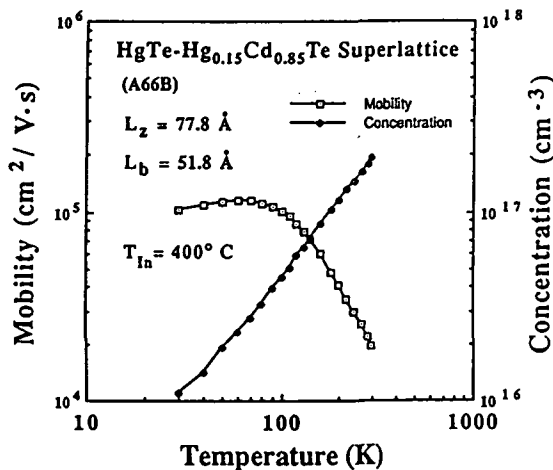
N. Otsuka, Purdue University

# HgTe-CdTe SUPERLATTICES

## Structural Properties: X-Ray Diffraction

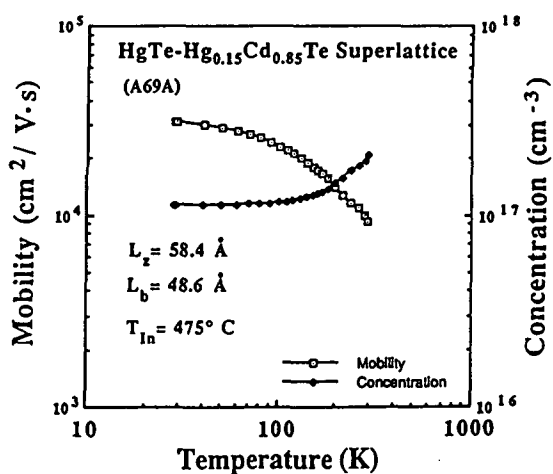
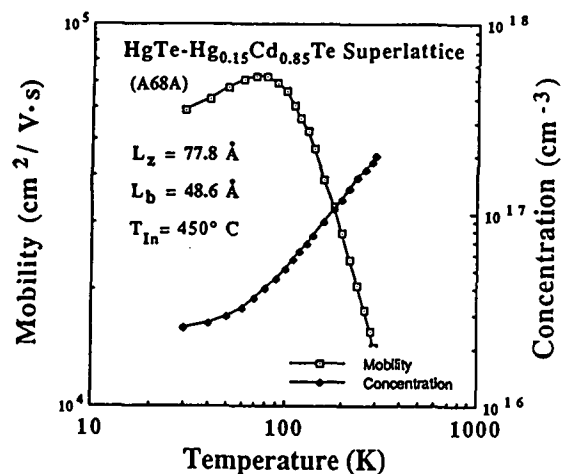


## Substitutional Doping: n-Type (Indium)

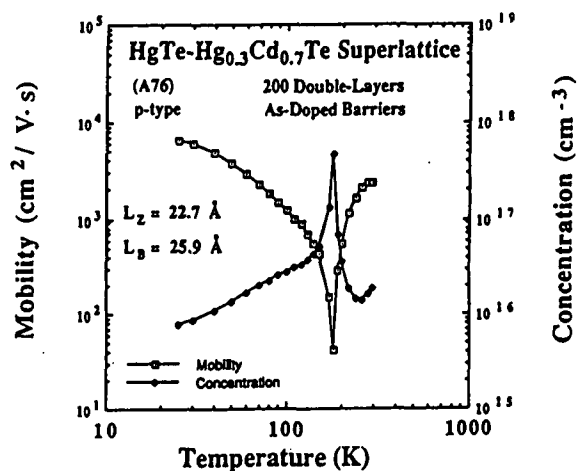
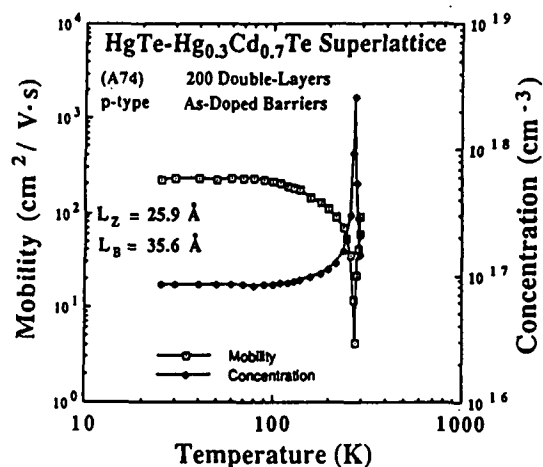


# HgTe-CdTe SUPERLATTICES

Substitutional Doping: n-Type (Indium)

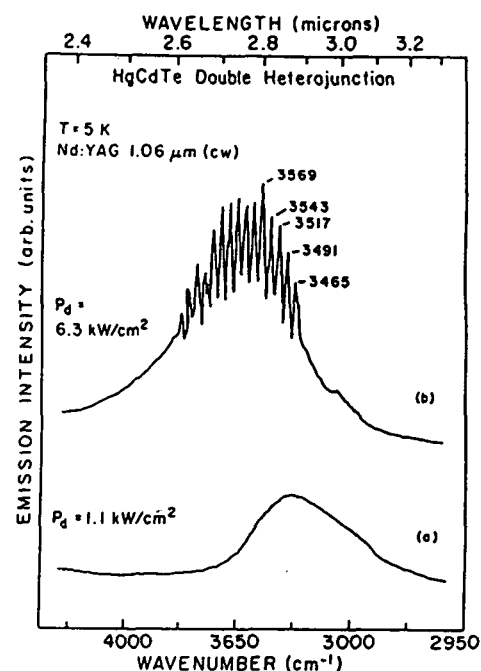
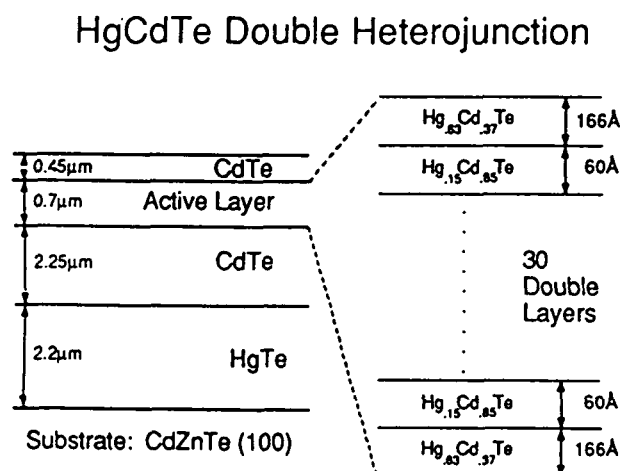


## Substitutional Doping: p-Type (Arsenic)



# HgCdTe-CdTe SUPERLATTICES

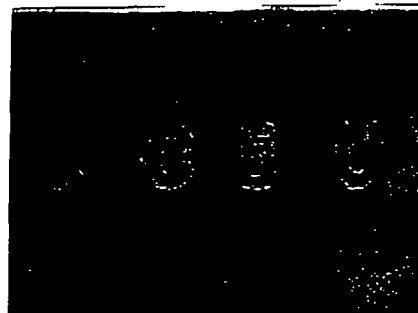
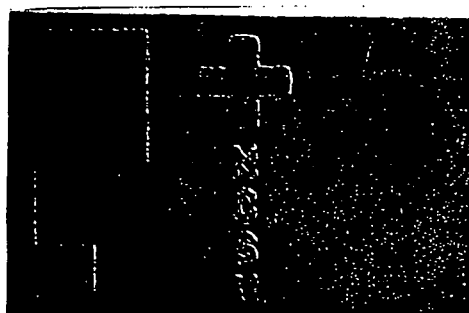
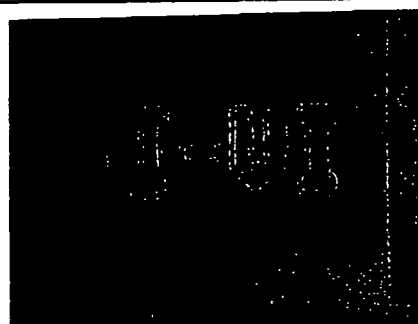
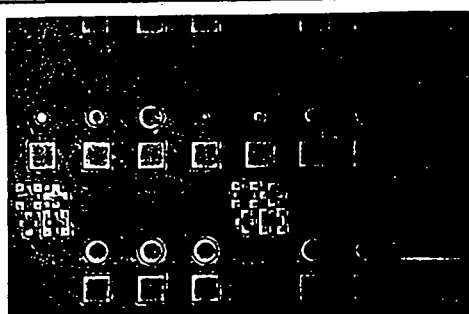
## Stimulated Emission



DARPA

Selective-Area Epitaxy of HgTe-CdTe Superlattices

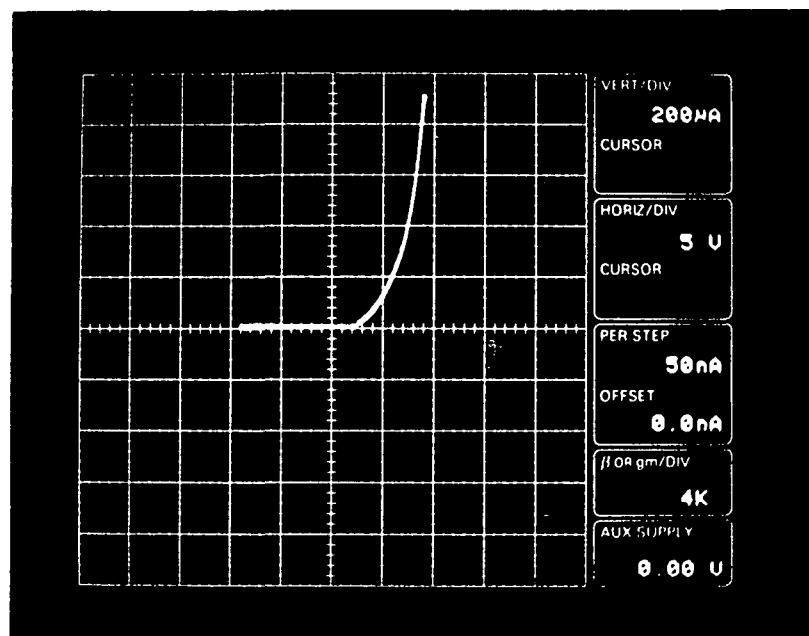
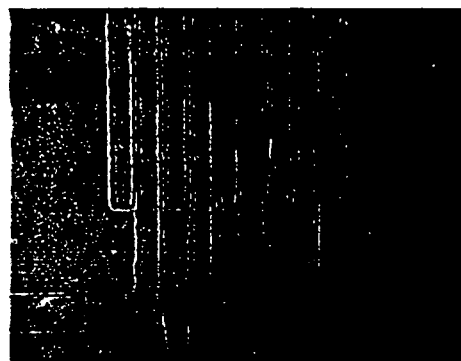
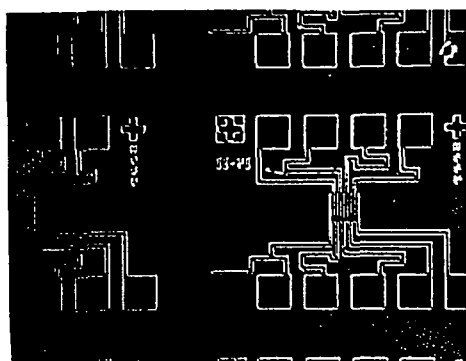
NCSU

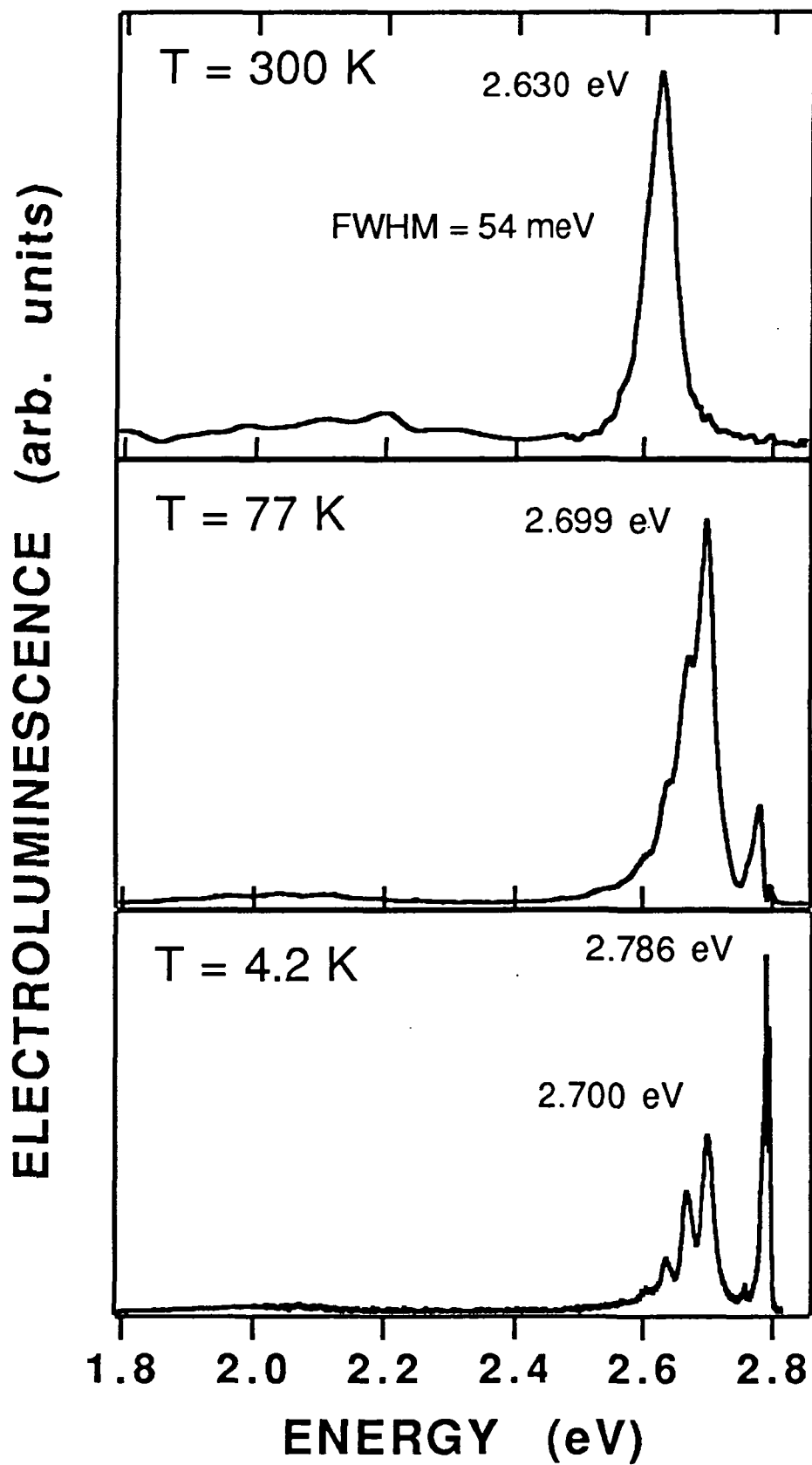


# Selective-Area Epitaxy of HgTe-CdTe Superlattices

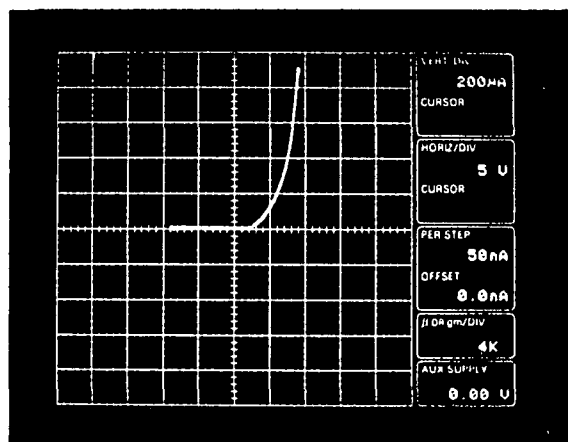
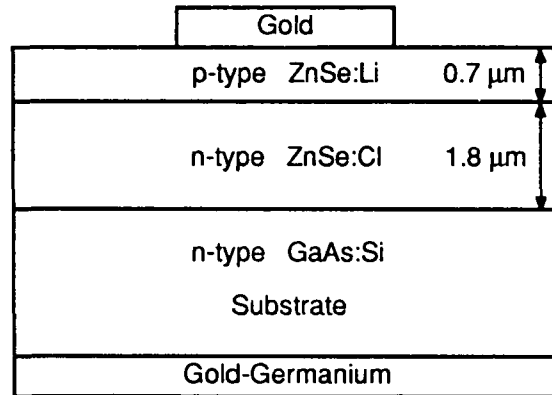
Growth Parameters: CdZnTe Substrates,  $T_s = 150^\circ\text{C}$ ,

Applications: Multicolored Sources and/or Detectors;  
Optical Waveguides; Light Modulators









## HgTe-CdTe SUPERLATTICES

### Summary of Properties

- AN INTERESTING INFRARED QUANTUM STRUCTURE
- SUPERLATTICE HAS MANY DIFFERENT STATES WHICH EXHIBIT VERY DIFFERENT PROPERTIES
- A VARIABLE BAND GAP STRUCTURE AS PREDICTED
- EXHIBITS LARGE ABSORPTION IN INFRARED REGION
- EXCELLENT ELECTRICAL PROPERTIES
- EXCELLENT STRUCTURAL PROPERTIES
- SHORT MINORITY CARRIER LIFETIMES (10 - 20 ns )
- DETECTOR APPLICATIONS: VLWIR REGION (18 - 24  $\mu\text{m}$ )